L413035

COLEGIO DE GEOLOGOS BOLIVIA

COMPAÑÍA MINERA DEL SUR

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Oruro, octubre de 2004

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TEMPORAL CORRELATION BETWEEN MINERAL DEPOSITS FORMATION AND REGIONAL OROGENIC EVENTS IN THE SW AMAZONIAN CRATON

Mauro C. Geraldes, Nely Palermo
Tektos–Grupo de Pesquisa em Tectônica, Faculdade de Geologia, UERJ, Rua São Francisco Xavier 524, Maracanã. 20550-013 Rio de Janeiro (RJ), Brazil
Jorge S. Bettencourt, Wilson Teixeira
Instituto de Geociências, USP, Rua do Lago 562, Cidade Universitária. 05508-900 São Paulo (SP), Brazil
Marcia A. S. B. Pinho, Renato D. Neder
Departamento de Geologia, Universidade Federal de Mato Grosso-UFMT. Av. Fernando Correia da Costa s/n, Cuiabá (MT), Brazil.
Richard Saenz, Paola Mancilla and Gabriela L. V. Mattos
Instituto de Investigaciones Geologicas y del Medio Ambiente, Universidad Mayor de San Andres. Campus Universitário, Calle 27 Zona Cota-Cota, 591. La Paz, Bolivia.

INTRODUCTION

A variety of mineral deposits characterizes the SW Amazonian craton, including the states of Rondônia and Mato Grosso (Brazil) and Bolivia territory. Deposits of this area include polymetallic veins, zoned hydrotheral alteration, magmatic and VMS types. The main mineral deposits are: the Moriru Au deposit; the Expedito Zn-Cu deposit; the Cabaçal Zn-Au deposit; the Puquio Norte Au deposit; the Rondonia Sn Province; and the Au deposits of Pontes e Lacerda region. Several minor occurrences are described in the region, such as Au prospects in Rondonia and Mato Grosso states, and younger (Mesozoic) diamond deposits comprised of the Juina (MT) and Colorado do Oeste (RO) kimberlites and sedimentary covers. This work constitutes a tentative correlation of mineral deposits age formation and orogenic events of the SW Amazonian craton during Paleo- and Mesoproterozoic times.

The tectonic environment provides a basis for understanding the distribution and origin of mineralization in space and time. In addition, the distribution of ore deposits through geological time allows defining the correlation between orogenic events and mineralizing processes. The determination of radiometric dating is an important tool to define a metalogenetic models of mineral deposits. Although the age of many deposits cannot be attributed to only one cycle of formation, because the measured ages may reflect not only syngenetic mineralogy, but also epigenetic hydrothermal overprint. By other hand, ages of mineral deposits may be constrained by direct radiometric dating and by considering the age of the host-rocks.

Four main accretionary periods can be established for the continental crust evolution of the SW part of the Amazonian craton. According to this general evolution the region has been divided in geochronological provinces: the Ventuari-Tapajós (2.20 Ga to 2.0 Ga); the Rio Negro-Juruena (1.79 Ga to 1.52 Ga) comprising two orogenic cycles (1.79-1.74 Ga Alto Jauru and the 1.58-1.52 Ga Cachoeirinha orogens); the Rondonian-San Ignácio encompassing the 1.51-1.48 Ga Rio Alegre orogen, the 1.45-1.42 Ga Santa Helena orogen and the 1.41-1.32 Ga San Ignácio orogen. Finally, the youngest Sunsás province comprises metasedimentary sequences (1,1-1.0 Ga Nova Brasilândia and 1.0 Ga Aguapeí orogens), and granitoids (1.0 Ga Sunsás orogen). This study is a tentative of recognition of time-bond characteristics of major SW Amazonian craton mineral deposit and their correlation with crustal accretionary processes. For this purpose we describe geologic information about mineral deposits of this area, including type of mineralizations, tectonic setting, host-rocks and ages.

THE ALTO JAURU OROGEN

The Cabaçal gold deposit is located in the SW Amazonian craton, Mato Grosso State, Brazil, where the Alto Jauru orogenic rocks (U-Pb ages from 1790

Ma to 1744 Ma) and Cachoeirinha orogenic rocks (U-Pb ages from 1580 Ma to 1520 Ma) occur. The mineralization is hosted by felsic volcanic and volcanoclastic rocks and occurs as: (i) bands concordant with the mylonitic foliation, (ii) breccias, (iii) quartz-carbonate veins and (iv) disseminated. The ore is polymetallic and comprised of chalcopyrite, pyrite, marcasite, pyrrhotite, sphalerite, and minor galena, bismuth, selenides and tellurites. The mineralization is related to hydrothermal alteration and includes quartz, chlorite, carbonate, sericite and biotite.

CRATONIC VOLCANIC COVERS

The Moriru Au deposit located in the NW of Mato Grosso state is hosted by acidic to intermediary volcanic rocks ascribed to intra-plate event comprised of bimodal magmatism dated by U-Pb at 1796-1773 Ma (U-Pb in zircon). The mineralization is related to felsic volcanic rocks with intense hydrothermal alteration characterized by sericitization, chloritization, carbonatation and silicification. The mineralization is chiefly disseminated and comprises pyrite, chalcopyrite, galena and ilmenite with 1.26 ppm of Au.

THE CACHOEIRINHA OROGEN

Granitic rocks of the Cachoeirinha orogenic event have widespread distribution in the Jauru region (Mato Grosso state-Brazil) where granitoids yielded U-Pb ages about 1580-1520 Ma. Six U-Pb and Sm-Nd analyses in granitoid rocks of the Cachoeirinha suite yielded ages of 1587-1536 Ma and TDM model ages of 1.88-1.75 Ga (εNd values of –0.8 to +1.0). In addition, three post-tectonic plutonic rocks yielded U-Pb ages from 1485-1389 Ma (TDM of 1.77-1.74 Ga and εNd values from –1.3 to +1.7). Variations in major and trace elements of the Cachoeirinha suite rocks indicate fractional crystallization process and magmatic arc geologic setting. These results suggest the following interpretations: (1) The interval of 1590-1390 Ma represents an important magmatic activity in SW Amazonian craton. (2) TDM and arc-related chemical affinity support the hypothesis that the rocks are genetically associated with a east-dipping subduction zone dipped east under the older (1.79-1.74 Ga) continental margin. No mineral deposit is reported correlated to this orogenetic event at this moment.

THE RIO ALEGRE OROGEN

The volcano-sedimentary rocks of the Rio Alegre terrane occur in the SW Amazonian Craton and comprise mafic and ultramafic volcanic rocks, chemical sedimentary rocks and mafic to felsic intrusive rocks metamorphosed at green-schist facies. Petrographic, chemical and isotopic studies allowed to subdivide the complex in three subunits: Minouro formation (base) comprises abundant basic-ultrabasic volcanic rocks and subvolcanic intrusive rocks associated with cherts and banded iron formations. Chemical data indicated an ocean-floor tectonic setting for the origin of these rocks; Santa Isabel formation (intermediary) comprises intermediate and acid lavas and pyroclastic rocks. Chemical results indicated an island arc setting for their origin, which is corroborated by the intermediate rocks U-Pb zircon ages of 1509-1503 Ma and TDM ages of 1.54 Ga and 1.48 Ga and εNd(t) values from +3.7 to +4.1 suggesting a mantle-derived magma origin. The São Fabiano formation (top) is composed of metasedimentary rocks with chemical signature similar to that of the volcanic rocks, suggesting that the latter are the source of the metasedimentary rocks. The basic-ultrabasic intrusive rocks are differentiated gabbroic rocks and serpentinites. Chemical data indicated the influence of the fractional crystallization process in the evolution of these rocks. U-Pb zircon dating in these rocks yielded age from 1509 Ma to 1494 Ma and TDM of 1. 67 Ga to 1.48 Ga and εNd(t) values of +4.5 to +2.5 suggesting a mantle-derived magma. U-Pb zircon analyses carried out in associated intrusive basic and felsic rocks yielded ages of 1.48-1.46 Ga. TDM ages vary from 1. 53 Ga to 1.50 Ga and εNd(t) values from +3.7 to +4.1 suggesting a magmatic arc environment for their generation.

Up to the moment, there is not any reference to extensive exploration work carried on this terrane. However, it is important to remark that the rock association related to a ocean floor expansion is most favorable for metalic ocurrences such as Au, Cu, Ni, PGM and associated metals. This assertation is corroborated by the identified extensive banded iron formation, cherts, gossan and superficial Ni concentrations as in Morro do Leme and Morro Sem Boné (Colorado-MT), where garnieritic mineralization presents 1.4% of Ni.

THE SANTA HELENA OROGEN

Proterozoic basement rocks ascribed to Santa Helena orogen were initially considered as rocks of granitic composition. Later on, these granites were studied based on geochemical data and the associated granites classified as intraplate A-type granites. Additional geological, geochemical and geochronological studies on this unit carried on made it possible to recognize and propose the term Santa Helena Suite. The extensive arc-related magmatism, together with the new U-Pb ages provided a consistent documentation for this event, and no mineralization related to this units is reported.

THE SAN IGNÁCIO OROGEN

The San Ignacio Orogeny is an important spatial magmatism over eastern Bolivia, especially over the

Parágua Craton, where the c. 1300 Ma orogenic dates are preserved in both Rb/Sr and K/Ar system. The formation of the San Ignacio Schist Group (Rb/Sr metamorphic age of 1344 ± 18 Ma) was accompanied by a significant syn to post-tectonic granitoid magmatism represented by the potassic calc-alkaline complex (Rb/Sr ages about 1.32 to 1.28 Ga) and by the El Tigre alkaline Complex (1286 ± 46 Ma). Within San Ignácio Schists Group is found the greenstone belts denominated Guarayos, Puquio Norte, Zapoco and Nuflo Chavez.

The Puquio Norte greenstone belt is located in the southwestern sector of Bolivia within the San Ignacio schist domain and presents the main gold deposit (completely exploited) reported in Bolivian Precabrian. Other Au prospects include Guarayos, San Javier, Al Toro and Dom Mario. Puquio Norte deposit is hosted by volcano-sedimentary rocks comprised of schist, komatiitic basalts, chert, BIF and tholeitic pillow lavas. Locally occurs the Naranjal group, constituted by black shales, carbonatic filites, hematite banded iron formation and pelites metamorphosed at green-schist facies showing vertical foliation and milky secondary quartz parallel to the bedding. A second BIF facies contains chert, hematite secondary quartz and the introduction of milky or glassy quartz forming crossed veins or stock works, with association of sulfides (mainly arsenopyrite) and gold. Field relationships indicate that mineralizing hydrothermal solutions were coeval to deformational process and gold precipitation was correlated and controlled by banded iron formation occurrence.

NOVA BRASILÂNDIA OROGEN

The name Nova Brasilândia Metavolcano sedimentary sequence comprises a group of supracrustal rocks, amphibolite-facies metamorphites represented by mica-quartz schists, biotite paragneiss, calc-silicated rocks, and amphibolites, which occur within the Nova Brasilândia and Alta Floresta region (SE Rondônia), formerly recognized as Comemoração Epimetamorphites More recently it was redefined as a distinct tectonic unit and the limits extended to NE and SE regions of the state of Rondônia. Based on detailed geological and reconnaissance U/Pb and SHRIMP geochronological data, "Nova Brasilândia Group" comprises dominantly mafic association (metagabbro, metadiabase and amphibolite), metaplutonic-sedimentary sequence (biotite-feldspar quartz gneisses, mica schists and calc-silicate rocks), intruded by several high-level late tectonic A-type granite plutons.

Accretion of juvenile material related to a intracontinental rifting and a proto-ocean floor expansion, granite plutonism and thermal effects suggesting a continental margin arc, were interpreted by Rizzoto (1999) as correlated to the Sunsas Orogeny.

The Nova Brasilandia Group is the host for a member of mineralized areas and Au, PGE, Pt, Ni, Zn and Sn ocurrences which were identified.

a) Dissemined Au either in metabasic rocks or associated to shear zones in metasedimentary rocks.

b) Ni-Cu sulphides and PGE associated to basic bodies either as disseminated or microfractures infill. The main sulphide phases are represented by pirite, pyrrotite and smaller amounts of chalcopyrite, pentlandite, viplarite, bravoite, arsenopyrite and cobaltite.

c) Centimetric to metric Au-quartz veins controled by NW-SE regional trend and N40E microfactures, associated with hydrothermaly altered paragneiss. Dendritic or massive Au gneiss are commonly associated with ilmenite, pyrite, arsenopyrite, chalcopyrite, manganese and iron oxides.

ANOROGENIC GRANITES IN RONDONIA (THE RONDONIA TIN PROVINCE)

The magmatism ascribed to the Rondonian event in the Rondonia Tin Province comprises bimodal intraplate rapakivi suites intruded in the ca. 1.75-1.53 Ga Rio Negro/Juruena crust. The magmatism episodes are defined by U-Pb geochronology and represented by the following suites: the Santo Antônio-Teotônio (1406 Ma), Alto Candeias (1347 to 1338 Ma) and São Lourenço-Caripunas (1314 to 1309 Ma), Santa Clara Intrusive suite (1082 Ma); and Younger Granites of Rondonia (998 Ma to 991 Ma).

The Sunsas orogen in northern Rondônia region and adjacent areas (Mato Grosso and Amazonia states) spanned the time period between 1.15 to 0.97 Ga. It includes mainly a metamorphic imprint and deformation from 1156 to 1100 Ma and emplacement of rapakivi granites, mafic dikes and plutons between 1080 to 970 Ma in rocks of older geochronological provinces resulting in economically important Sn anomalies.

The Sn mineralization comprises cassiterite-rich greisen related to granites which compositions are mostly subalkaline, metaluminous to peraluminous and show geochemical features of A-type within-plate granites. The main Sn regional mineralizations are related to the Santa Clara Intrusive suite, which encompasses the granites from the following massifs: Santa Clara, Oriente Velho, Oriente Novo, and Manteiga. The older rock association is composed of porphyritic quartz-monzonite, monzonite and syenogranite with subordinated amounts of quartz-monzonite and less pyterlite. Biotite and minor hornblend are the main mafic minerals and zircon, apatite, ilmenite, magnetite, allanite, fluorite and sphene are essential minerals. A younger association in-

ciudes syenite, trachyte and peraluminous and peralkaline granites.

Isotopic analysis carried out in the granites related to tin mineralizations allow important constraints on their origin. The Younger Granites of Rondonia shows $\varepsilon_{Nd(t)}$ values of +0.33 to –3.25, T_{DM} between 1.66 to 1.73 Ga, $Sr_{(i)}$ in the range of 0.707 to 0.709, $\delta^{18}O$= +81 to 9.5 ‰ and has $^{206}Pb/^{204}Pb$ of 17.7-20.6 and $^{208}Pb/^{204}Pb$ of 37.3-43.2 indicating that older crustal rocks were clearly involved in granite genesis. Oxygen isotopes indicate a calc-alkaline magma component or assimilation of high-level crustal material. $^{40}Ar/^{39}Ar$ plateau ages on hornblende foliated granitic gneisses and augengneiss defined ages of 1156.2 ± 36 Ma and 1149.8 ± 35.5 Ma., respectively and suggest a Sunsas metamorphic overprint. The progressively slightly younger dates obtained on the biotites, 1001.5 ± 33 Ma and 912.8 ± 30.5 Ma, and more feldspar (antiphertite), record slow cooling rates during the proposed metamorphism and are consistent with K/Ar ages observed in the Younger Granites of Rondônia (1.08-1.00 Ga).

THE SUNSAS OROGEN

Sunsas granitoids include both syn- to late-kynematic granitoids related to shear zones and late to post-kynematic types with little or no signs of deformation. According to these authors, syn to late-kynematic types, which may be foliated, are mainly medium to coarse-grained biotite or biotite muscovite syenogranites. The granitoids may show gradational contacts with nebulitic Sunsas migmatites gneisses, foliated margins or mylonitic zones result of frictional melting and local anatexis along Sunsas shear zones. The observed units are: Espiritu Granite, Santa Catalina Zone Granites, Las Palmas Granitoids, La Palca granitoids, San Miguel Granite, Motacucito Granite, San Pablo Granite, El Carmen Granite, and Nomoca Granodiorite. Also, there are few syn-kynematic granitoids, which resemble deformed intrusive plutons such as La Palca granitoids of tonalitic composition and Nomoca Granodiorite, and subordinated monzonites and throndjenites.

The late to post-tectonic granitoids are aligned within the Sunsas Orogen across the San Diablo shear zone and are represented by the Casa de Piedra Granites, Talcoso and Tapeva Granites, and Salinas and Tasseoro Granites, and also in the southeast fringe by the San Pablo granodiorite, and Luma granite, but data is sparse in these bodies, and further studies are need. They are circular or oval in plane with intrusive contacts and little or no signs of internal foliation and dominantly medium to coarse-grained biotite monzogranites. Additionally, marginal swarms of crosscutting pegmatites and aplites are met in the country rocks. The observed field features indicate the granite emplacement occurred in a higher crustal level. The age measurements are still fragmentary and only the Casa de Piedra granite was dated by Rb/Sr at 1005 ± 12 Ma.

Most of the mineralization is associated with pegmatite bodies and aplite veins related to the post-tectonic granites of the Sunsas Orogeny, which affected the country schist rocks (Litherland et al., 1986). The pegmatites are of simple to complex composition, show a regional zoning, varying from tantalite-beryl to columbite-scheelite-beryl-topaz and cassiterite-topaz-fluorite-scheelite. Tin mineralization is reported in the Ascension de Guarayos tin field where it is associated with pegmatites of Sunsas age (1000 Ma), quartz vein and incipient greisenization. In this area the staniferous pegmatites are related to a syn to late-kinematic granites and to the adjacent metasediments.

THE AGUAPEI THRUST

The term "Sunsas Orogeny" designates a period of sedimentation that includes the older rocks erosion, deformation and metamorphism that encompasses the basement rocks and magmatism within the time interval 1300 to 950 Ma that took place in the SW Amazonian Craton and form the southern rim of the Parágua Craton. The deformation and metamorphism resulted in a W-NW trending Aguapei Thrust. Gold ores in the region of Pontes e Lacerda (MT) have been exploited in the SW Amazon carton from placer, lateritic and hydrothermal quartz vein deposits. Statistics of Mineral Production National Department, indicate a production of gold about 5 ton between 1991 and 1993. The gold ore bodies are hosted in contact of Aguapeí Group rocks and the basement represented by metavolcanic, gneiss-granite, quartzite, tonalites and granite units. Tectonics involves oblique overthrusting (from NE to SW) which led to formation of recumbent folds and thrusts (pathways for the mineralizing fluids), upright folds and faults with dominant strike-slip component. These unconfomities are potential sites for mineralization as in the main exploted deposits reported: São Vicente deposit Lavrinha eposit and Pau-a-Pique deposit.

CONCLUSIONS

The SW part of the Amazonian craton is a multi-orogen region formed between 1.8 and 1.0 Ga which experienced effects of successive magmatism, metamorphism and deformation responsible for the origin of mineral concentrations along the region. The results here presented allow to suggest a strong correlation between the time period of the tectonic events and the formation age of mineral concentrations of economic importance (Figure 1). In this way, each geologic environment is characterized by specific mineral deposit type and thereby provides constraints for regional exploration.

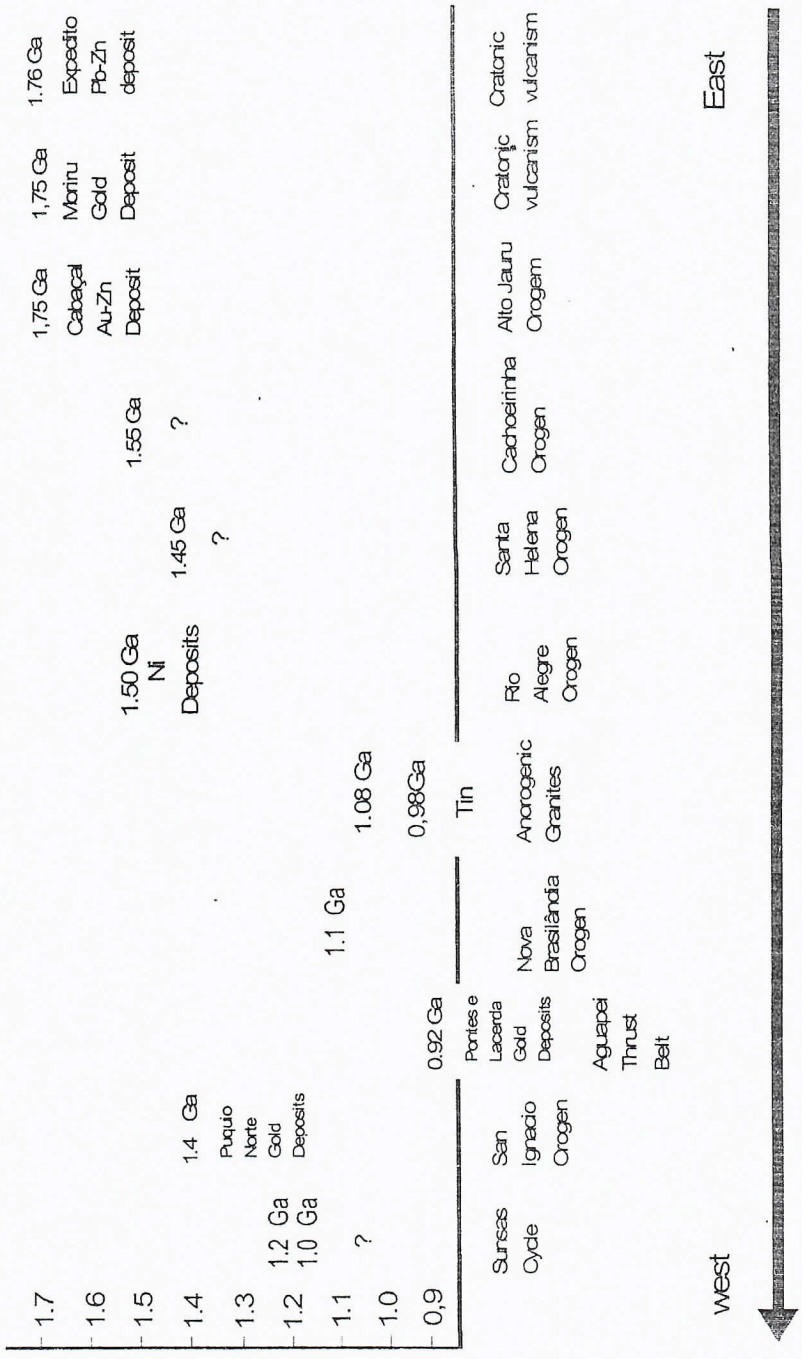

Figura 1. Chart correlating orogens and deposits.